BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B69 12031

SUBJECT: Use of Proposed Air Force Orbit-to-Orbit Shuttle (OOS) in NASA's Integrated Space Program - Case 710

DATE: December 10, 1969

FROM: A. E. Marks

ABSTRACT

A new upper stage for future earth orbital Air Force missions is being studied by the Aerospace Corporation. This stage is similar in size and function to the LM/B proposed for NASA's Integrated Space Program. The use of the contemplated Air Force stage, called orbit-to-orbit shuttle (OOS), in the NASA Integrated Plan is considered on the basis of propulsive performance, thermo-structural capability, and physical dimensions.

Although the various conceptual versions of the OOS have adequate propulsion performance to fulfill all the NASA missions, it may not be feasible to build a single stage that can fulfill both NASA and Air Force mission requirements. There is good reason to doubt the adequacy of the OOS thermo-structural systems in NASA missions, or the compatibility of the physical dimensions for both NASA and Air Force missions. Specifically, the structural loads imposed by NASA missions, and the meteoroid shielding and thermal insulation required by the long on-orbit lifetime, would reduce the stage mass fraction to the point where the Air Force missions could not be accomplished.

(NASA-CR-109783) USE OF PROPOSED AIR FORCE ORBIT-TO-ORBIT SHUTTLE /OOS/ IN NASA'S INTEGRATED SPACE PROGRAM (Bellcomm, Inc.) 23 p

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MEMORANDUM FOR FILE

INTRODUCTION

The Aerospace Corporation is currently conducting in-house studies on space propulsion modules for the Air Force, with design requirements and constraints imposed by the basic Space Transportation System (STS), also known to NASA as Space Shuttle. They are designing the stages for earth orbital missions only, but the stages considered are similar in size and functionally related to the LM/B Propulsion Module/Space Tug (Reference 1) in NASA's Integrated Space Program, (Reference 2). It seems only logical, therefore, to consider a single stage capable of performing both Air Force and NASA missions. This memorandum addresses the use of the Air Force stages for all proposed LM/B and space tug missions in the NASA program.

Both expendable and reusable stage concepts are being studied for the Air Force, but the reusable stage known as the orbit-to-orbit shuttle (OOS) is the stage of interest. This shuttle will operate between low earth and geosynchronous orbits.

GROUND RULES

A discussion of the Aerospace Corporation study guidelines and constraints is warranted since the major problems encountered in combining NASA and AF requirements are in the operating ground rules. The more critical guidelines are listed below:

1. The OOS will be designed for deployment in, and operation from, low earth orbit.

2. The OOS stage(s) (and payloads) will be carried to low earth orbit in the internal bay of the STS.

3. The OOS is to be designed to deliver single or multiple payloads to 24 hour orbits, and have the capability to return (sans payload) to the original low earth orbit. It will reenter the payload bay of the STS in LEO, and be returned to earth for maintenance and reuse. The OOS will be the passive element in remating with the STS.

The major implications of these ground rules are that the payload will be integrated to the OOS on the ground and no rendezvous or docking will occur in orbit prior to payload insertion. The OOS will be hung in tension in the space shuttle payload bay during launch. This will allow a very light structure to be used. Being launched inside the shuttle payload bay, the OOS will also be free of the aerodynamic and thermal loads during launch, again allowing a light structure to be employed.

The OOS, after payload insertion, will return to low earth orbit, remate with the space shuttle, and be returned to earth in the shuttle for refurbishment, refueling, and reuse. As a result, on-orbit staytime requirements are short, and the meteoroid shielding and thermal propellant storage requirements are minimized. All these factors allow a high OOS mass fraction to be attained.

The maximum diameter of the OOS is dictated by the shuttle payload bay diameter, since the OOS must be launched by the shuttle. This could cause problems if the shuttle payload diameter is restricted to 15 feet.

Both the LM/B and OOS designs are very preliminary, and the performance to be presented should be viewed as comparative and not absolute.

DESIGN DATA

Two OOS vehicles are being studied. One is required to provide 12,900 fps ΔV to its payload and return empty. The maximum gross weight including the payload is 50,000 pounds. The second is a stretched version of the first which has a ΔV capability of 14,300 fps, and a maximum gross weight including payload of 80,000 pounds. Initial weight estimates of the smaller stage show it to be about 42,000 pounds if the mass fraction is 0.9. The same mass fraction was estimated for the other candidate stage which weighed 73,300 pounds. The design data for this stage was then placed in a digital computer program and the resulting mass fraction was 0.88, with the stage weighing 75,000 pounds. Table 1 summarizes these two candidate configurations. Obviously, the stage designs are not too consistent since the smaller stage has a higher mass fraction.

TABLE I

Initial Weight Estimates

	Baseline Stage	Stretched Stage	LM/B PM
Design ΔV, fps	12,900	14,300	--
Maximum Gross Weight (Including Payload), lbs.	50,000	80,000	--
Mass Fraction λ	0.90	0.88	0.80
Stage Gross Weight, lbs.	42,000	75,000	50,000
Engine Specific Impulse (RL-10 Mod.), sec	444	444	460

The propulsion system for these stages is currently thought to be modified RL-10 engines. The engines must be modified for reusability and throttling, and have a thrust of 15,000 pounds at a 5:1 mixture ratio.

In comparison, the LM/B propulsion module has a gross weight of 50,000 pounds and a conservative estimation of its mass fraction is 0.80 (with landing gear). It also uses modified RL-10 engines but the performance is uprated as well to 460 seconds specific impulse. The engine must also be capable of deep throttling.

MISSION ANALYSIS

The mission requirements for a LM/B and space tug in NASA's Integrated Space Program are summarized in Table 2. It will be used as upper stages for the Saturn V launch vehicle, as a space tug in LEO and geosynchronous orbits, as an unmanned planetary injection stage, and as a lunar surface-to-orbit shuttle vehicle. The specific requirements are:

TABLE 2

LM/B and Space Tug Mission Requirements

Mission	Objective
4th Stage on Saturn V	Deliver large PL to lunar orbit
4th & 5th Stages on Saturn V	Deliver large PL to lunar surface
Space Tug	Operation around space stations with varying PL
Planetary Injection	Inject automated spacecraft on planetary trajectories
Lunar Surface-to-Orbit	Operate both manned and unmanned on one way and round trips between lunar orbit and surface

The stages are to be reusable in all missions except when used as upper stages on the Saturn V launch vehicle, or landing large payloads (i.e. $\gtrsim$ 50,000 lb) on the lunar surface.

PERFORMANCE RESULTS

Upper Stages on Saturn V

Both the baseline and stretched versions of the OOS were analyzed as upper stages on the 120,000 pound TLI payload Saturn V to determine lunar orbit and lunar surface payloads via direct launch from earth. In all cases, the performance exceeded that obtained by using LM/B PM's as Saturn V upper stages. This is due primarily to the hypothesis that the OOS's have a very high structural efficiency. Landing gear were added to the landing stage OOS's amounting to 5 percent of the landed weight. The effective mass fractions for the OOS stages were then both 0.84. The LM/B PM has landing gear included in its mass fraction estimation. Table 3 shows the performance of the OOS stages, and the LM/B PM for comparision, to lunar orbit and to the lunar surface.

TABLE 3

Saturn V Performance With Additional Upper Stages

TLI ΔV = 10,000 fps
LOI ΔV = 3,600 fps*
S-V TLI Payload = 120,000 lbs

	Baseline OOS	Stretched OOS	LM/B PM
Lunar Orbit PL, lbs (4 stage S-VC)	95,000	101,000	92,000
Lunar Surface PL, lbs (5 stage S-VC)	54,500	58,500	52,000

Space Tug Operations

A space tug is required to operate about earth orbital space stations in support of satellite placement, retrieval, and inspection missions. The tug will move payloads through altitude and plane changes. Figures 1 thru 4 show the performance of the baseline and stretched OOS's when operating from low earth orbit and geosynchronous stations. The tug capabilities are for round trips with the same payload. LM/B PM performance is also shown for comparison.

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*Apollo 12 LOI ΔV = 3059 fps; Apollo 11 LOI ΔV = 3081 fps (free return).

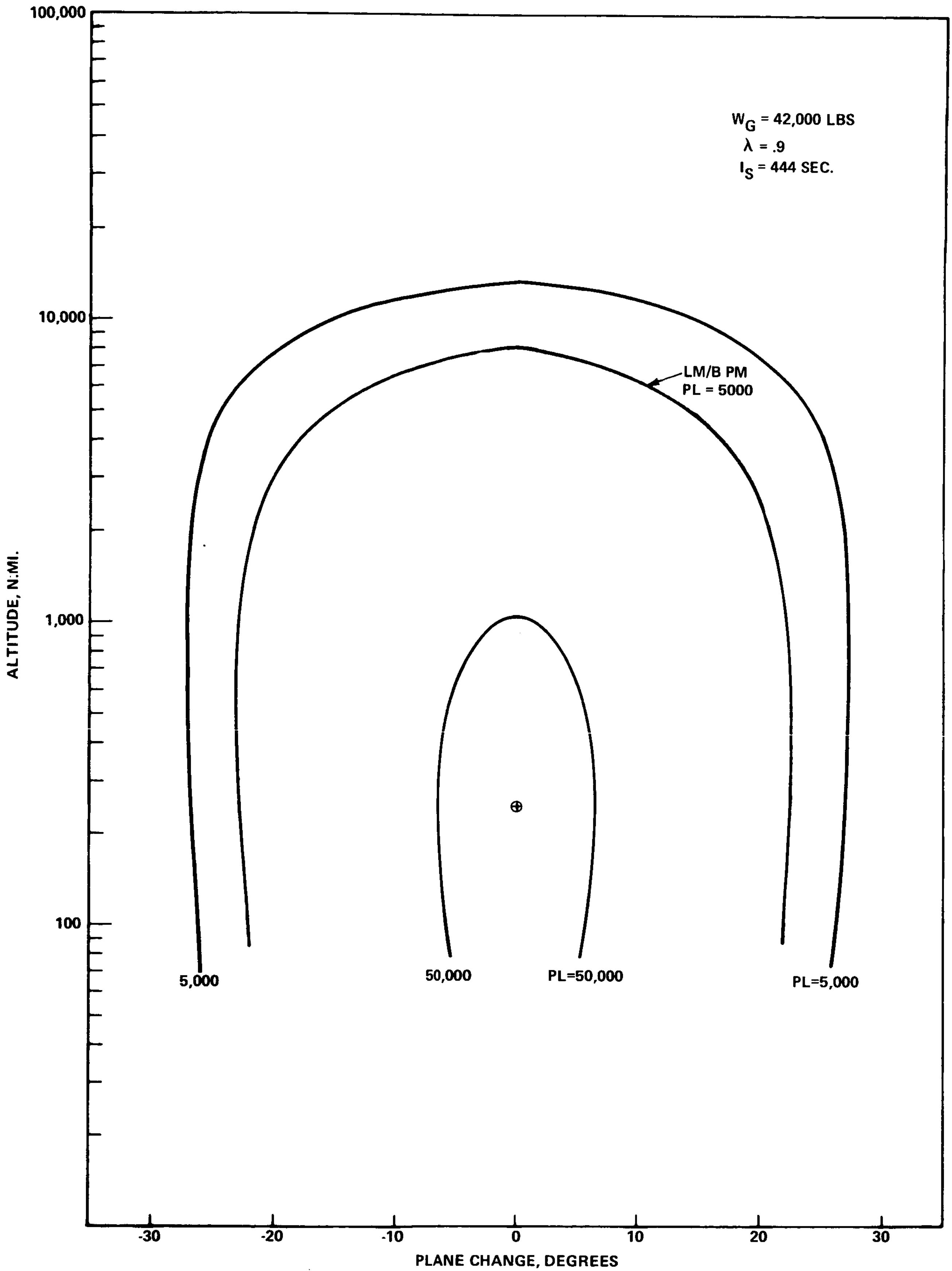

FIGURE 1 - SPACE TUG CAPABILITY
(ROUND TRIP FROM LEO)

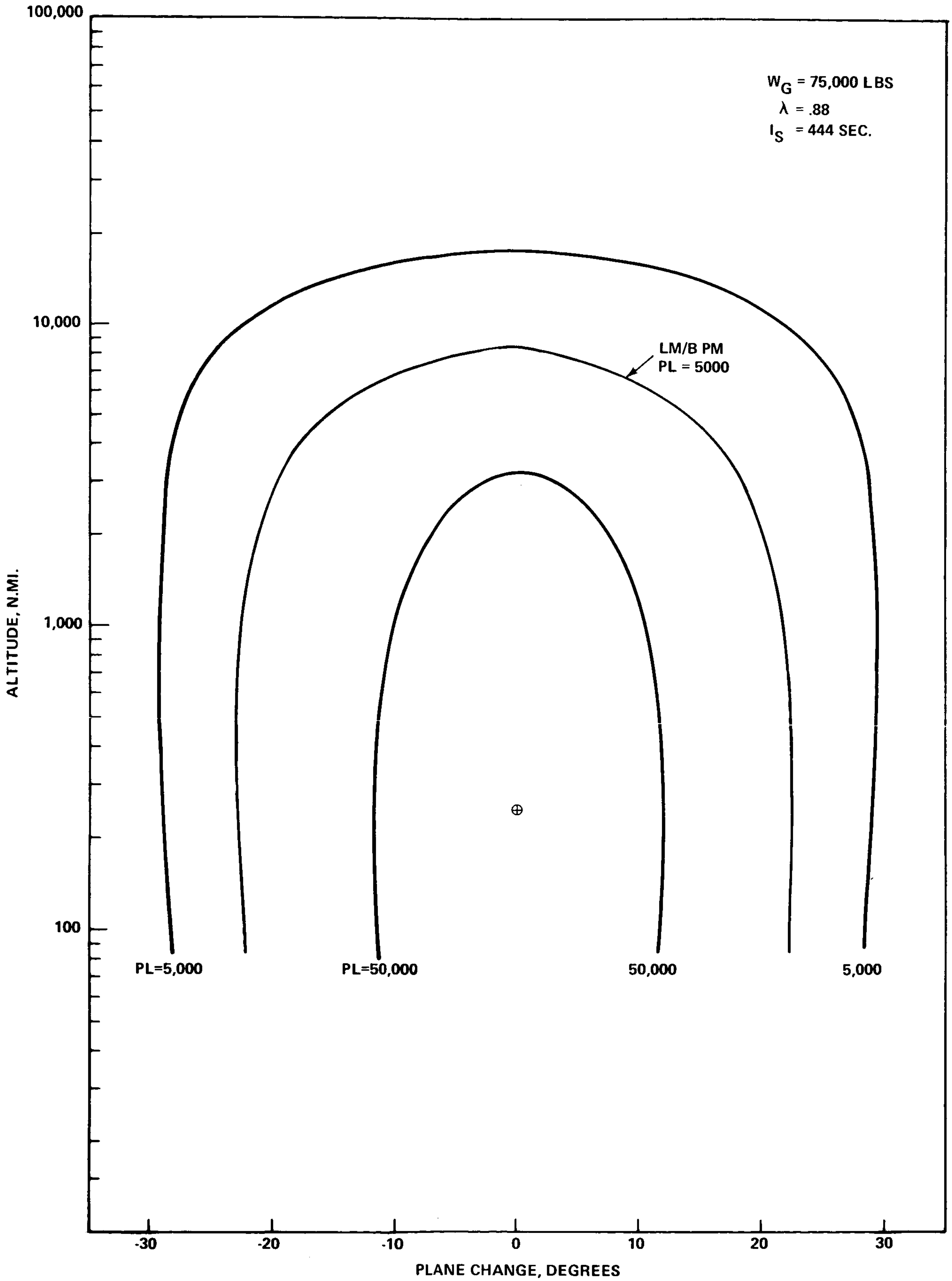

FIGURE 2 - SPACE TUG CAPABILITY
(ROUND TRIP FROM LEO)

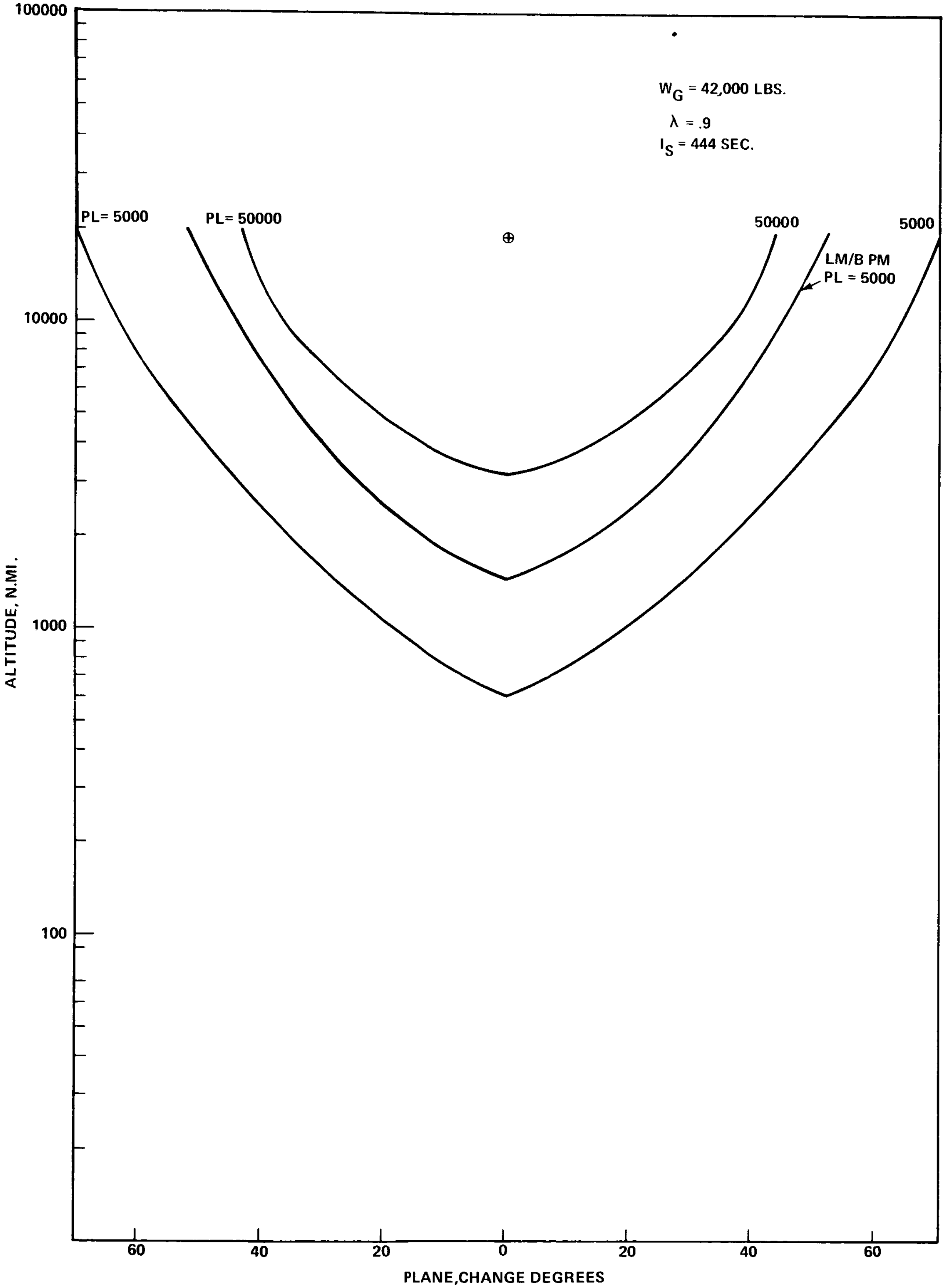

FIGURE 3 - SPACE TUG CAPABILITY (ROUND TRIP FROM GEOSYNCH ORBIT)

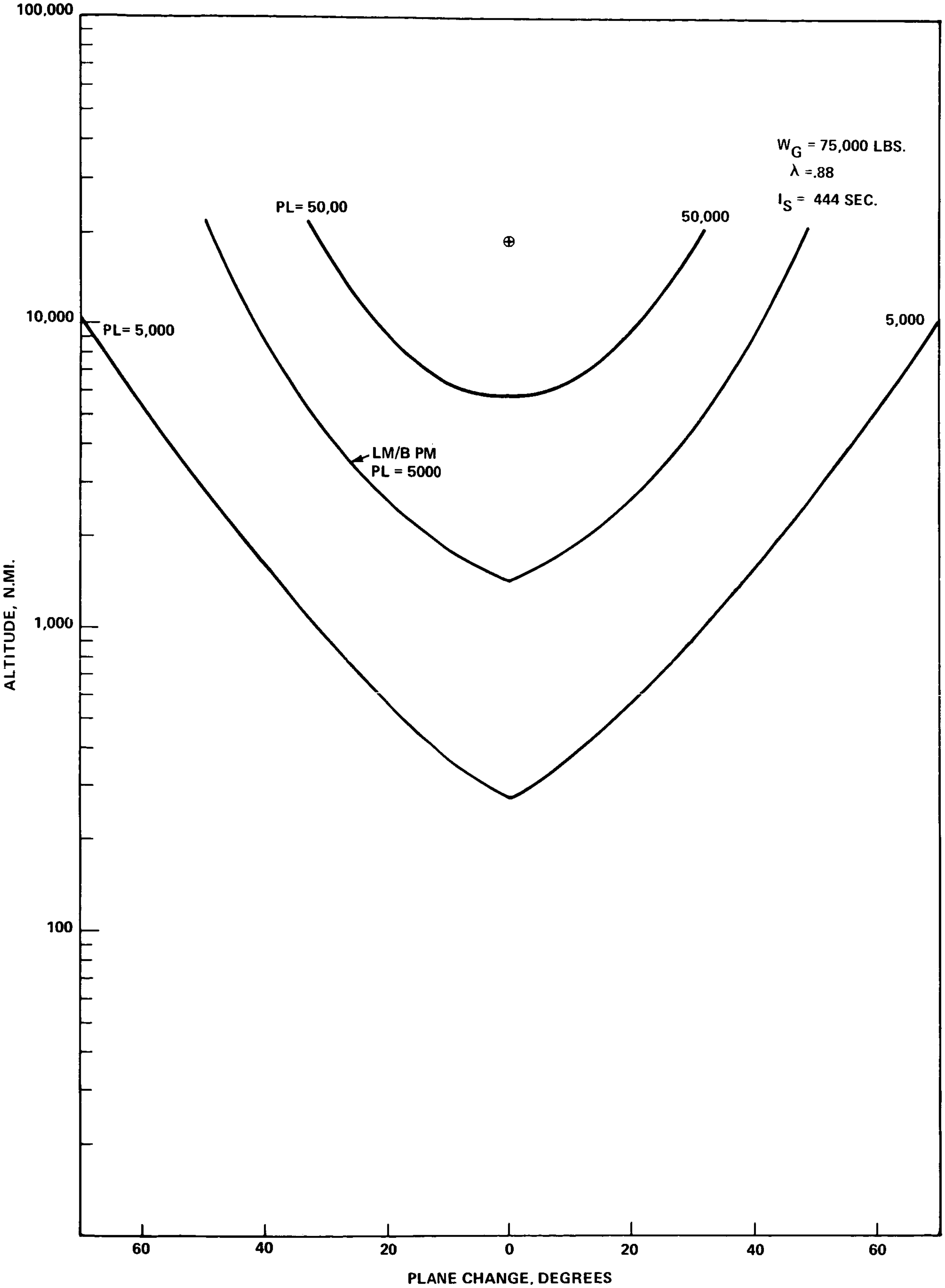

FIGURE 4 - SPACE TUG CAPABILITY
(ROUND TRIP FROM GEOSYNCH.)

Automated Planetary Probe Injection

A mode of injecting automated planetary probes onto their trajectories is described in References 3 and 4. Briefly it consists of bringing the probes to low earth orbit in the STS, integrating the payload onto the injection stage already in orbit, and then launching the probes toward their destination. Depending on payload size and ΔV requirements, one or more stages may be used and one or both recovered. Figures 5 and 6 show the performance of both OOS stages and the required payload (Balanced Base Planetary Program post 1976). It can be seen that a single recoverable OOS will perform just about all inner planet missions, while a single expendable OOS will perform all the outer planet missions. The use of the LM/B PM for these missions necessitated two stage injection for all missions. The stages used for inner planet missions were both recovered, while only the first stage for the outer planet missions were recovered.

Lunar Surface-to-Orbit Shuttle

The use of both OOS stages, with landing gear added, for round trips from lunar orbit to the surface and back have been analyzed. The stretched OOS off-loaded to 50,000 pounds gross weight was also analyzed. This is to allow two stages to be brought to lunar orbit with one Saturn VC launch (PL to lunar orbit is around 100,000 pounds). This reasoning was also the basic rationale behind the selection of a 50,000 pound LM/B, Reference 1. Figure 7 shows the shuttle capability of these stages as a function of payload and specific impulse. The LM/B performance is included for comparison.

It can be seen that all these stages can adequately perform the lunar mission requirements. The 7000 pound minimum up payload is the Space Crew Capsule.

PARAMETRIC ANALYSIS

The structural loads that would be imposed on the OOS by the lunar landing mission, and the requirement as a fourth stage on Saturn V, will be significantly greater than those with which the OOS was originally designed. The structure will now be subjected to significant compressive and bending loads, and will similtaneously be exposed to boost aero heating. Also, long mission durations will require sufficient meteoroid shielding and thermal protection to assure mission success. All these factors will tend to decrease the Aerospace estimated OOS mass fraction. Since no detailed analysis has been made on the OOS for NASA missions, a typical propulsion module was evaluated parametrically for the lunar surface to orbit missions, the planetary injection missions, and the Saturn VC mission where the PM is the 4th stage of the Saturn V.

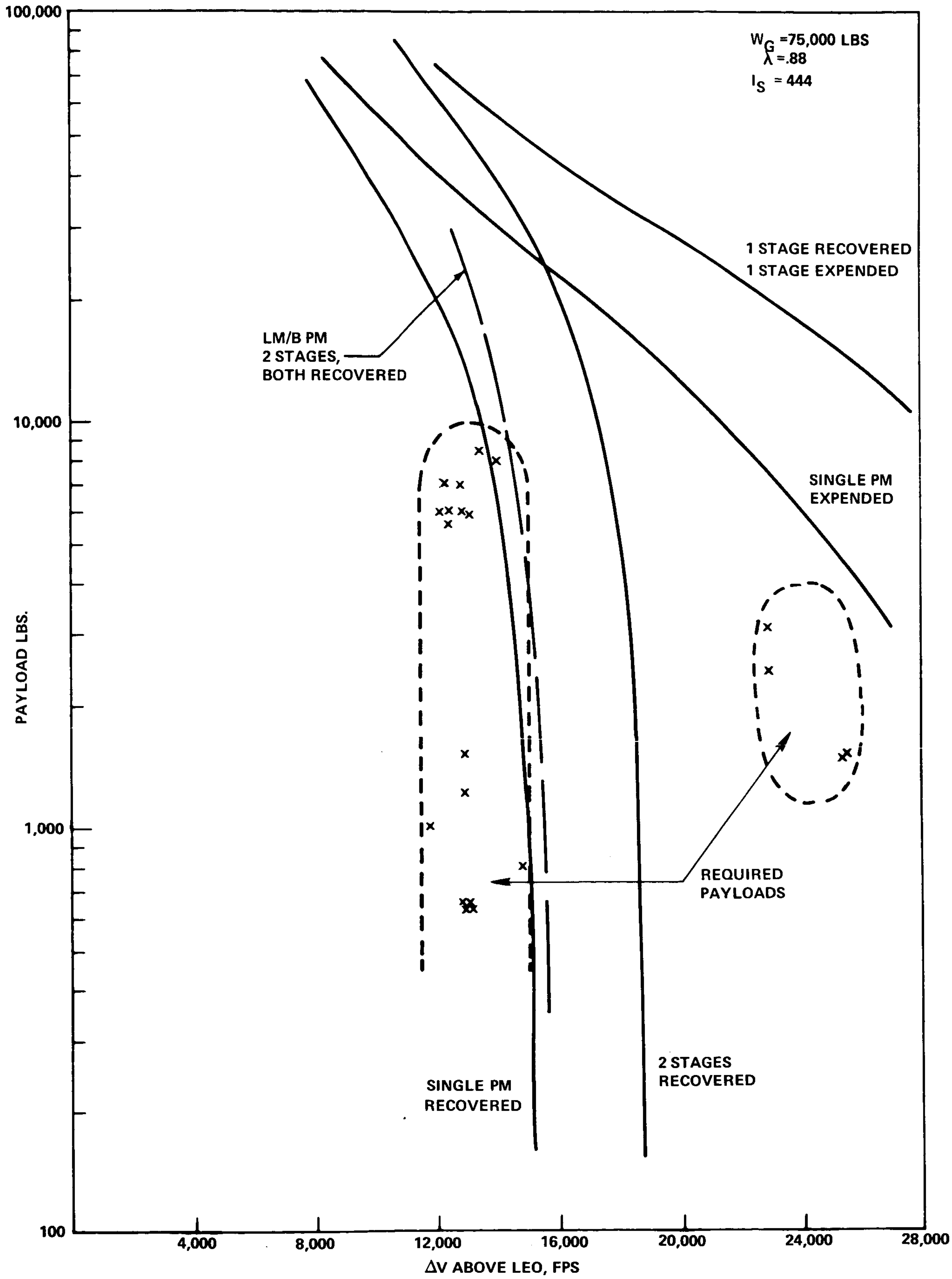

FIGURE 5 - PLANETARY INJECTION PERFORMANCE

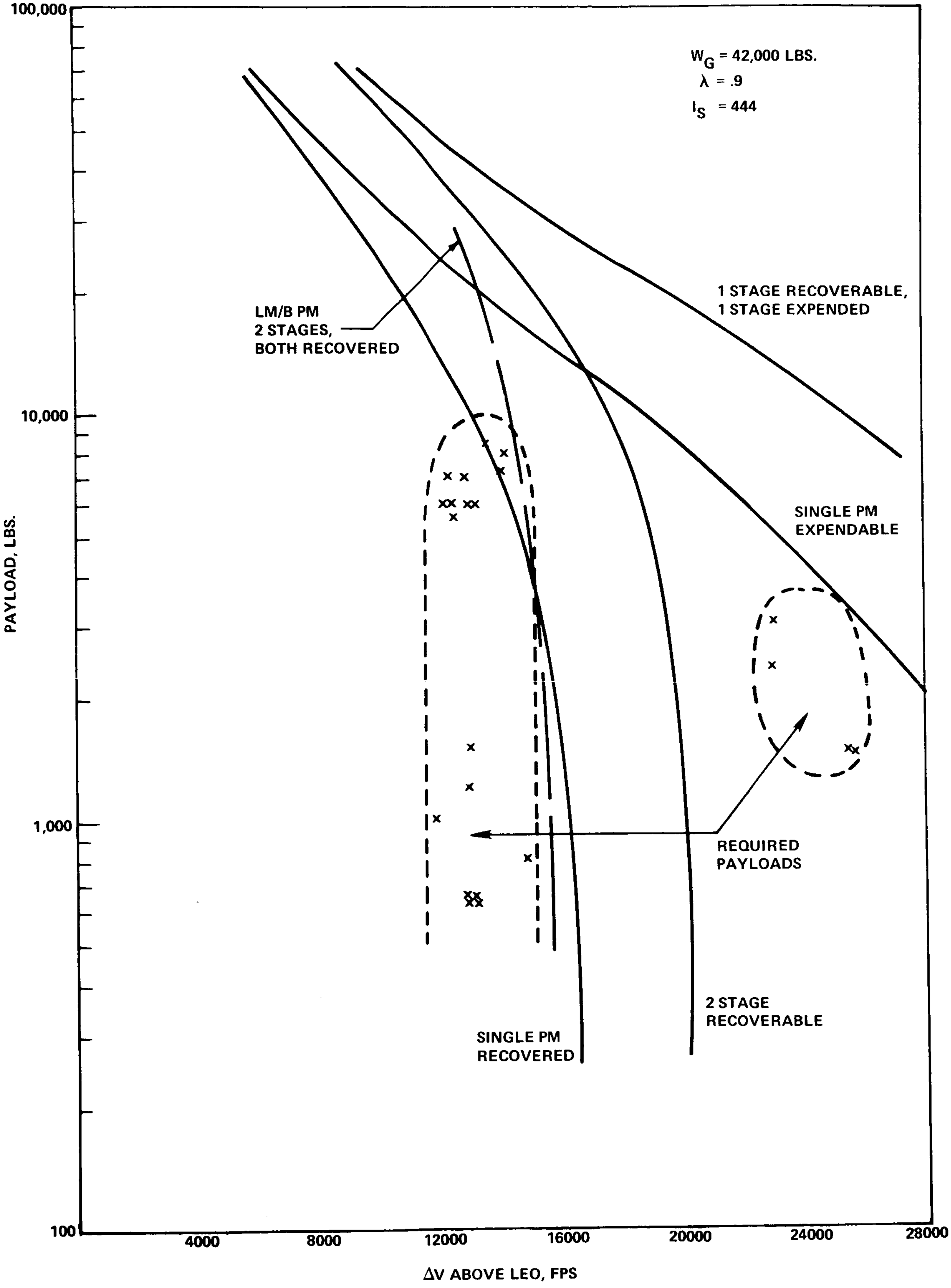

FIGURE 6 - PLANETARY INJECTION PERFORMANCE

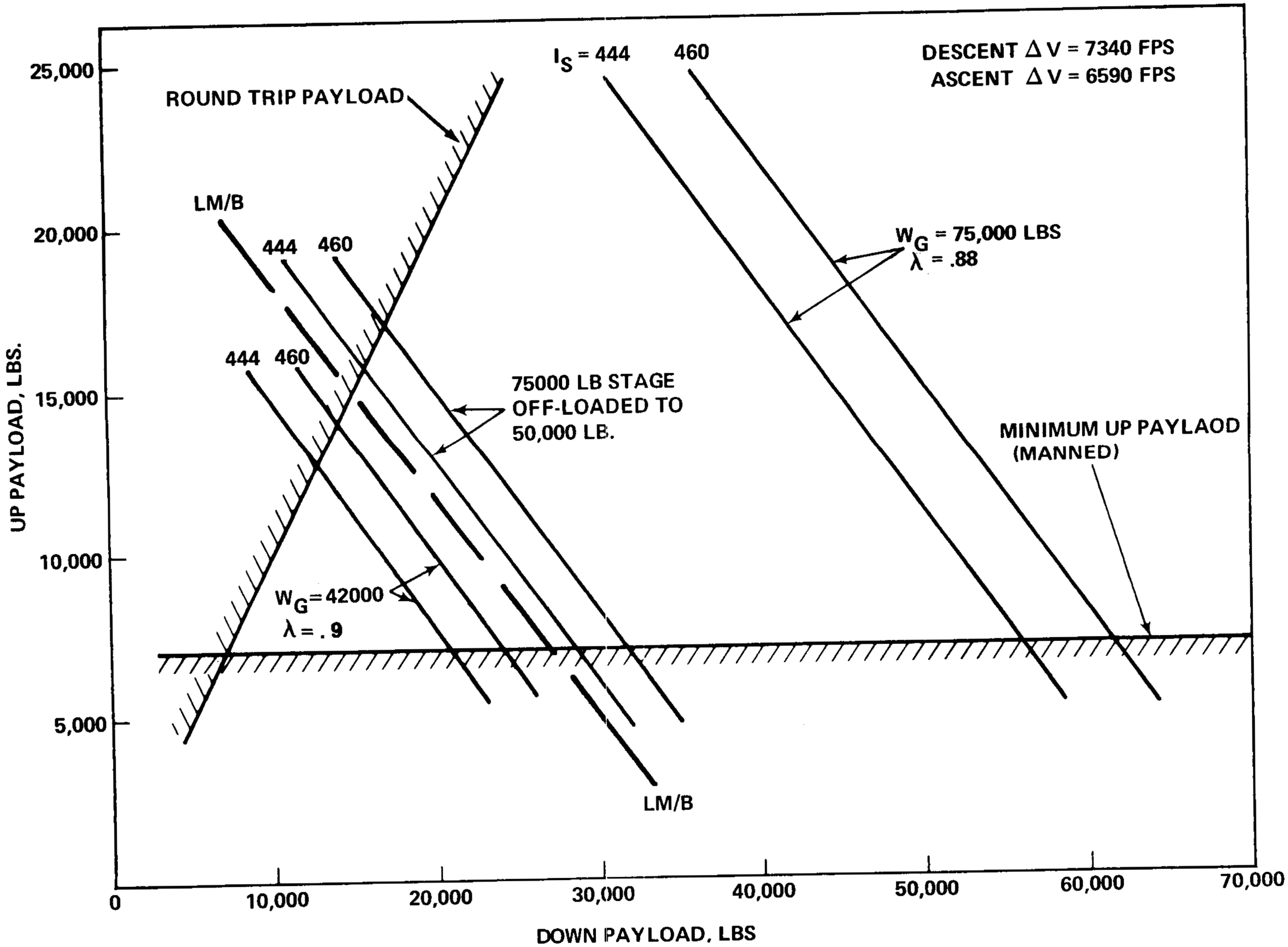

FIGURE 7 - LUNAR SURFACE - TO - ORBIT PERFORMANCE
(ROUND TRIP)

Figure 8 presents the lunar orbit-to-surface-to- orbit performance for a 50,000 pound stage and varying mass fractions. It can be seen that 1% decrease in λ costs about 2,000 pounds of down payload for a minimum 7,000 pounds up payload.

Figures 9 and 10 present the escape payload capability of a 50,000 pound PM with varying mass fractions. A recoverable single stage injection, Figure 9, could perform all inner planet mission requirements if the mass fraction is at least 0.88. With a mass fraction of at least 0.80, a two stage injection with both stages recovered will fulfill all the inner planet mission requirements, Figure 10. It can be seen that even if the mass fraction is 0.9, the outer planet missions still cannot be accomplished with two stage recoverable injection; one stage must be expended.

The performance of the PM as a fourth stage on Saturn V was evaluated with varying mass fraction and stage gross weight. Figure 11 shows the variation in delivered payload to lunar orbit with mass fraction, with two stage performance also shown. About 1% of λ was equivalent to 750 pounds of payload. This is not a very significant number. Figure 12 shows the delivered lunar orbit payload variation with stage gross weight. It can be seen that very little gains are attainable after a stage gross weight of around 40,000 pounds.

The use of two stages on top of the Saturn V was also analyzed for lunar orbit payload capability. The results are shown in Figures 11 and 13. Roughly, a 10,000 pound payload increase can be attained with a 5 stage Saturn V over a 4 stage Saturn V.

Thermo-Structural and Physical Compatibility

Based on the preceding analysis, the mass fraction of the OOS can be considerably reduced and still meet NASA mission requirements. However, if the mass fraction is only slightly reduced, the OOS will not accomplish the Air Force missions. An estimation of the increased weight and resulting mass fraction necessary for NASA missions is made from Reference 6. The weight per square foot of surface area for a combined meteoroid shielding, structure, and thermal protection system is about 2 pounds per square foot. This assumes a .99 probability of no penetrations, a "bumper factor" of 5, and an on-orbit lifetime of one year. This structure will be adequate to sustain launch loads on top of the Saturn VC, and the loads encountered in lunar landings. The thermal insulation system will be sufficient to minimize propellant boiloff for all contemplated missions. Landing legs will be added for lunar landing missions, and will weigh about five percent of the gross landed weight. The resulting mass fraction for the basline OOS is summarized below.

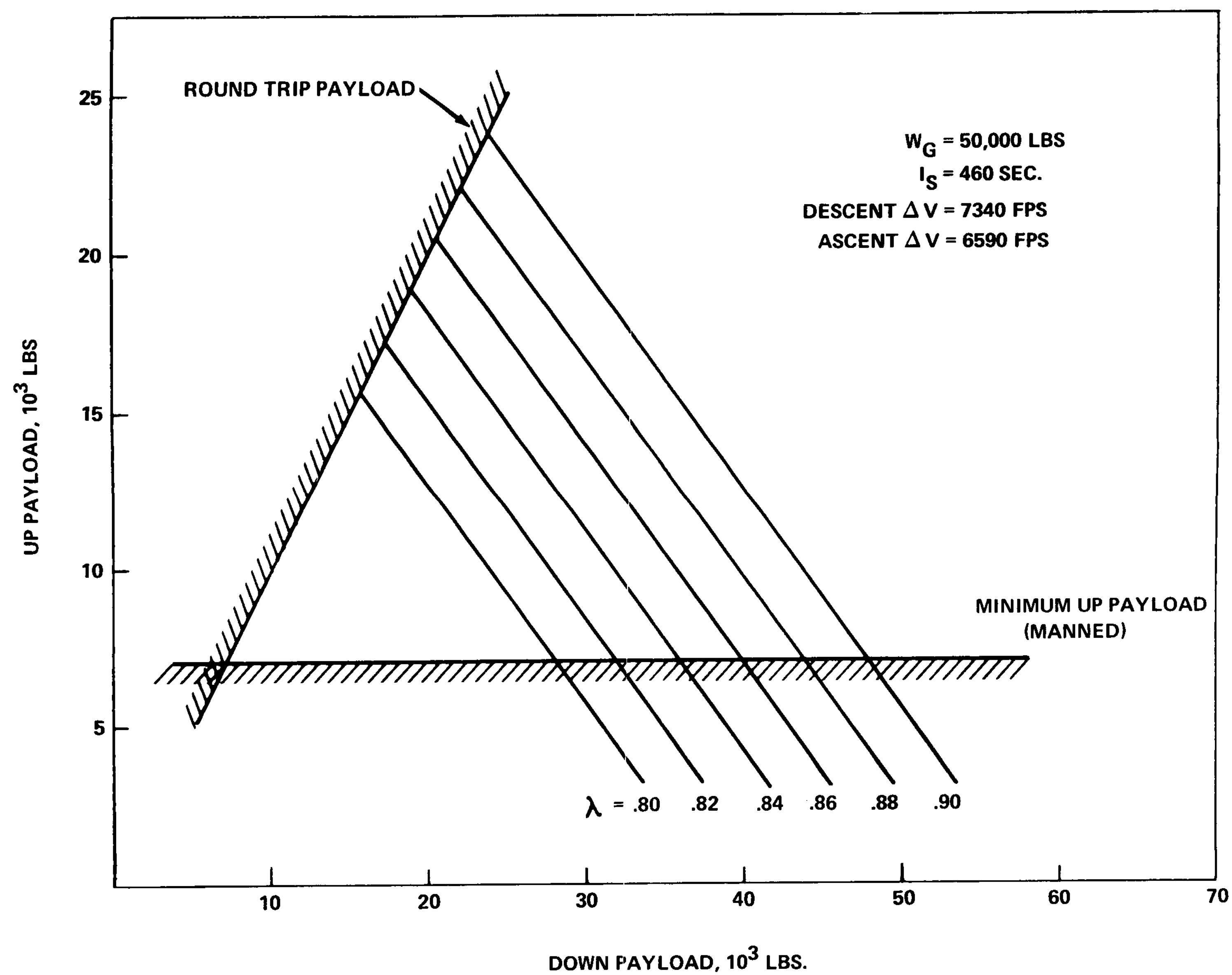

FIGURE 8 - LUNAR ORBIT - SURFACE - ORBIT PERFORMANCE MASS FRACTION EFFECTS

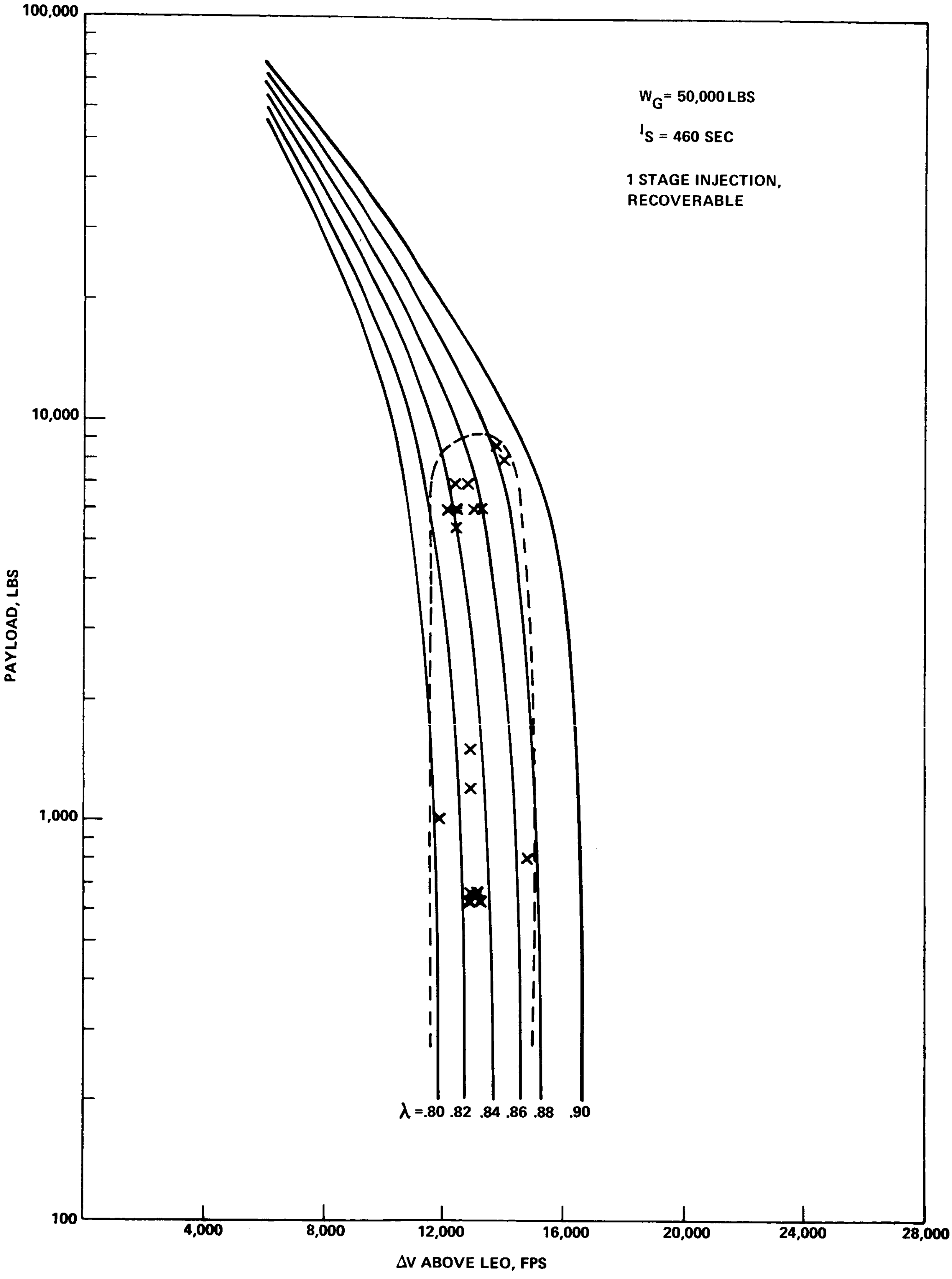

FIGURE 9 - PLANETARY INJECTION PERFORMANCE
MASS FRACTION EFFECTS

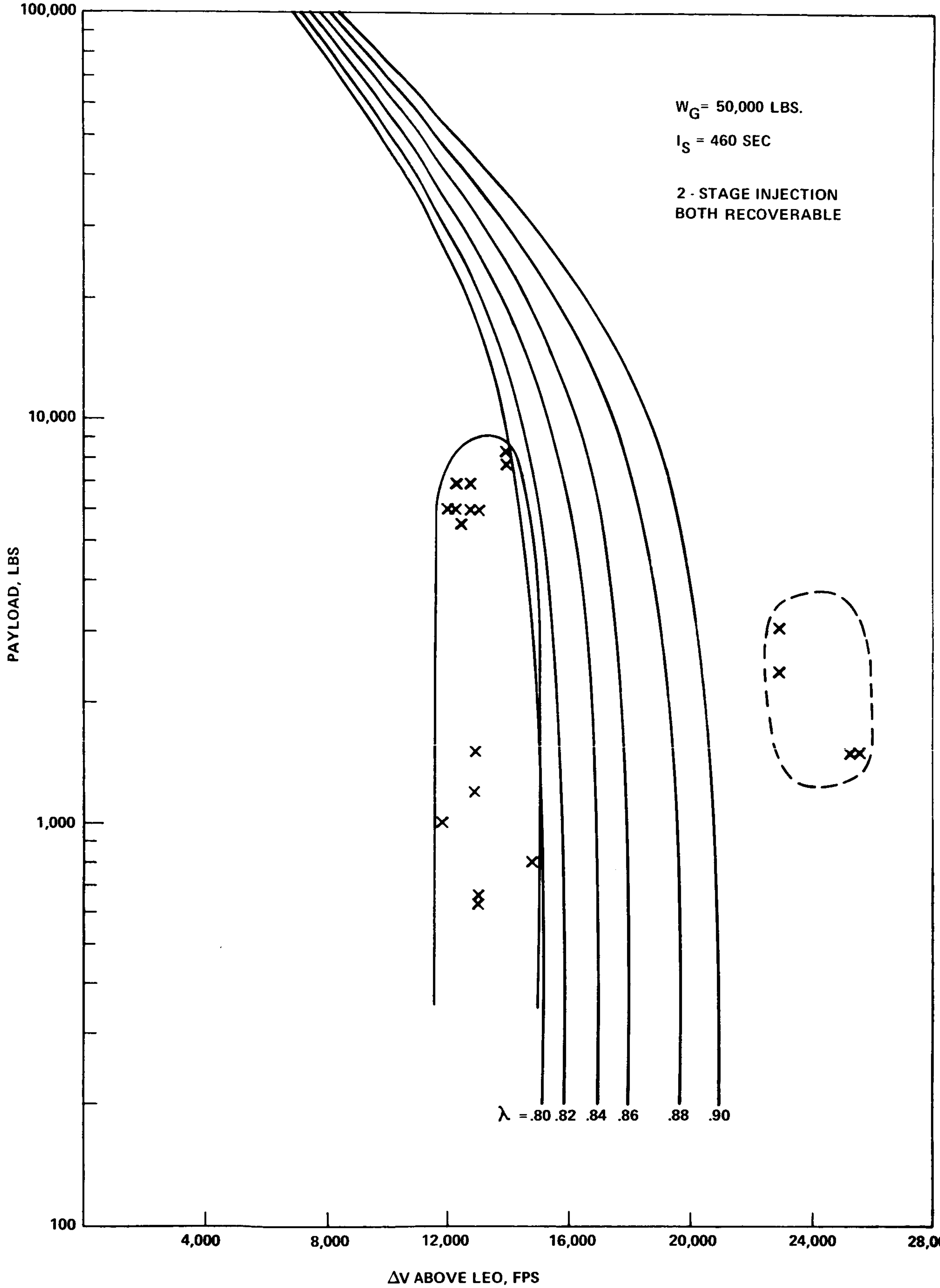

FIGURE 10 - PLANETARY INJECTION PERFORMANCE
MASS FRACTION EFFECTS

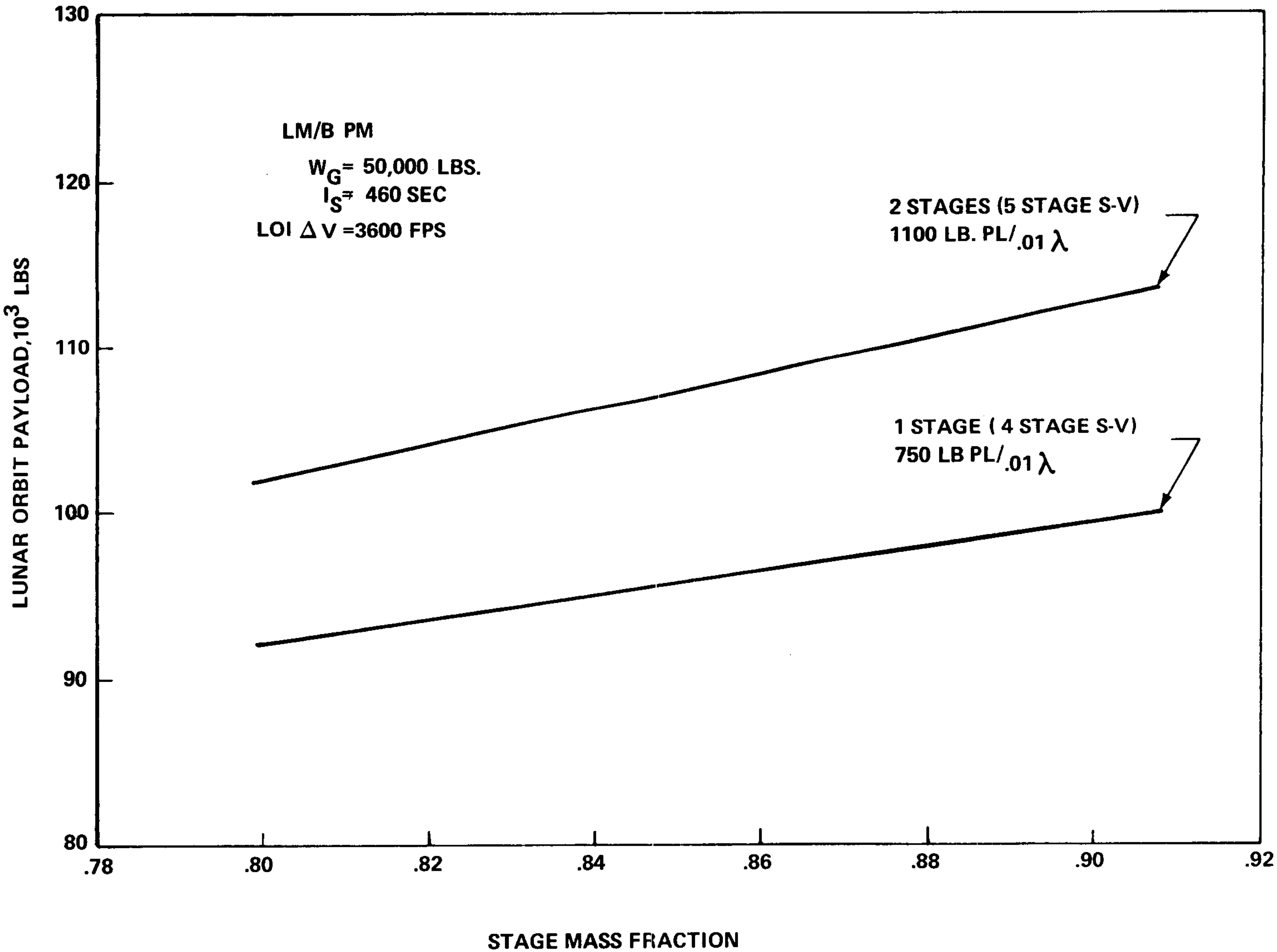

FIGURE 11- DELIVERED PAYLOAD TO LUNAR ORBIT AS UPPER STAGES ON SATURN V

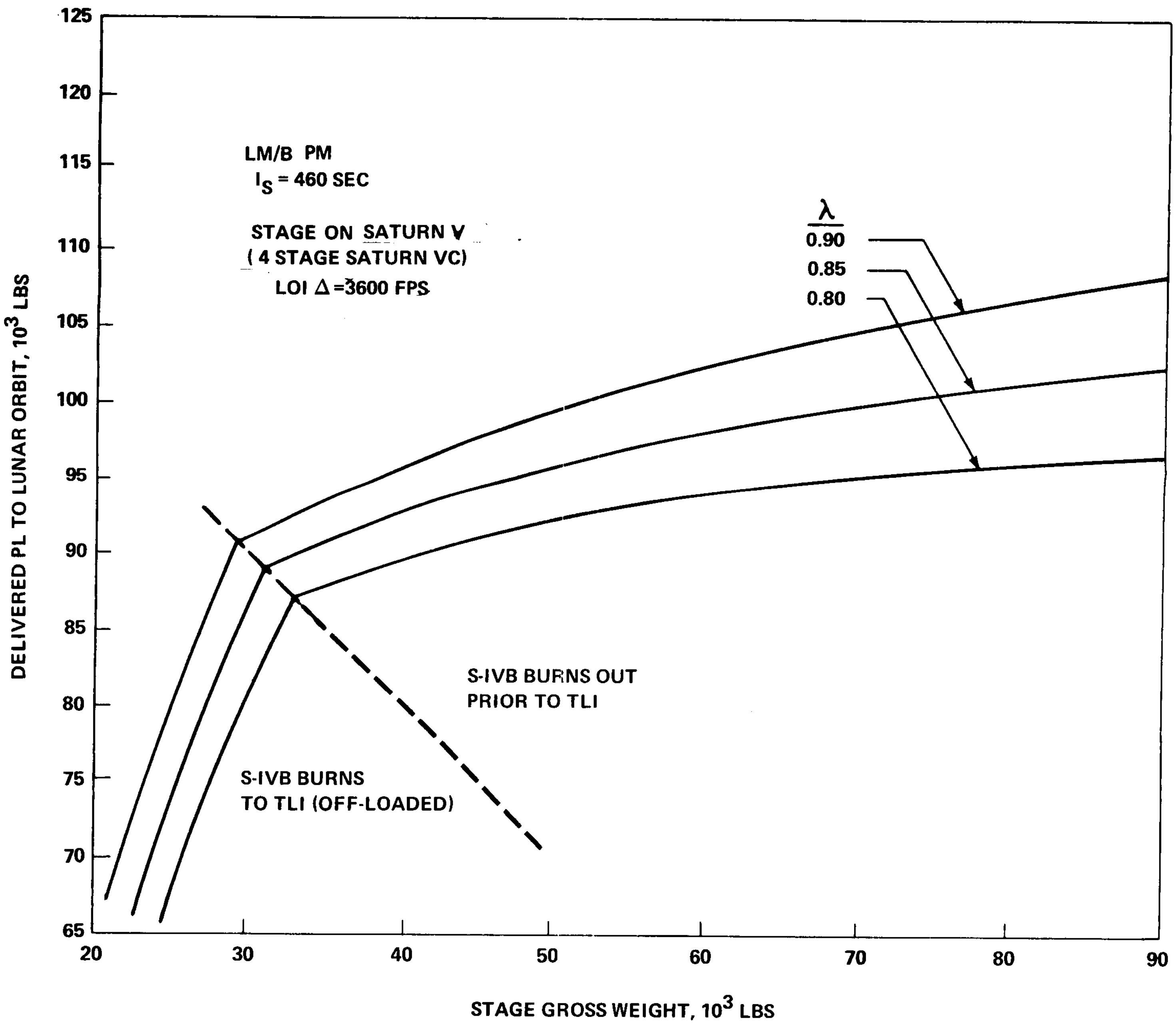

FIGURE 12 - DELIVERED PAYLOAD TO LUNAR ORBIT
4 STAGE SATURN VC

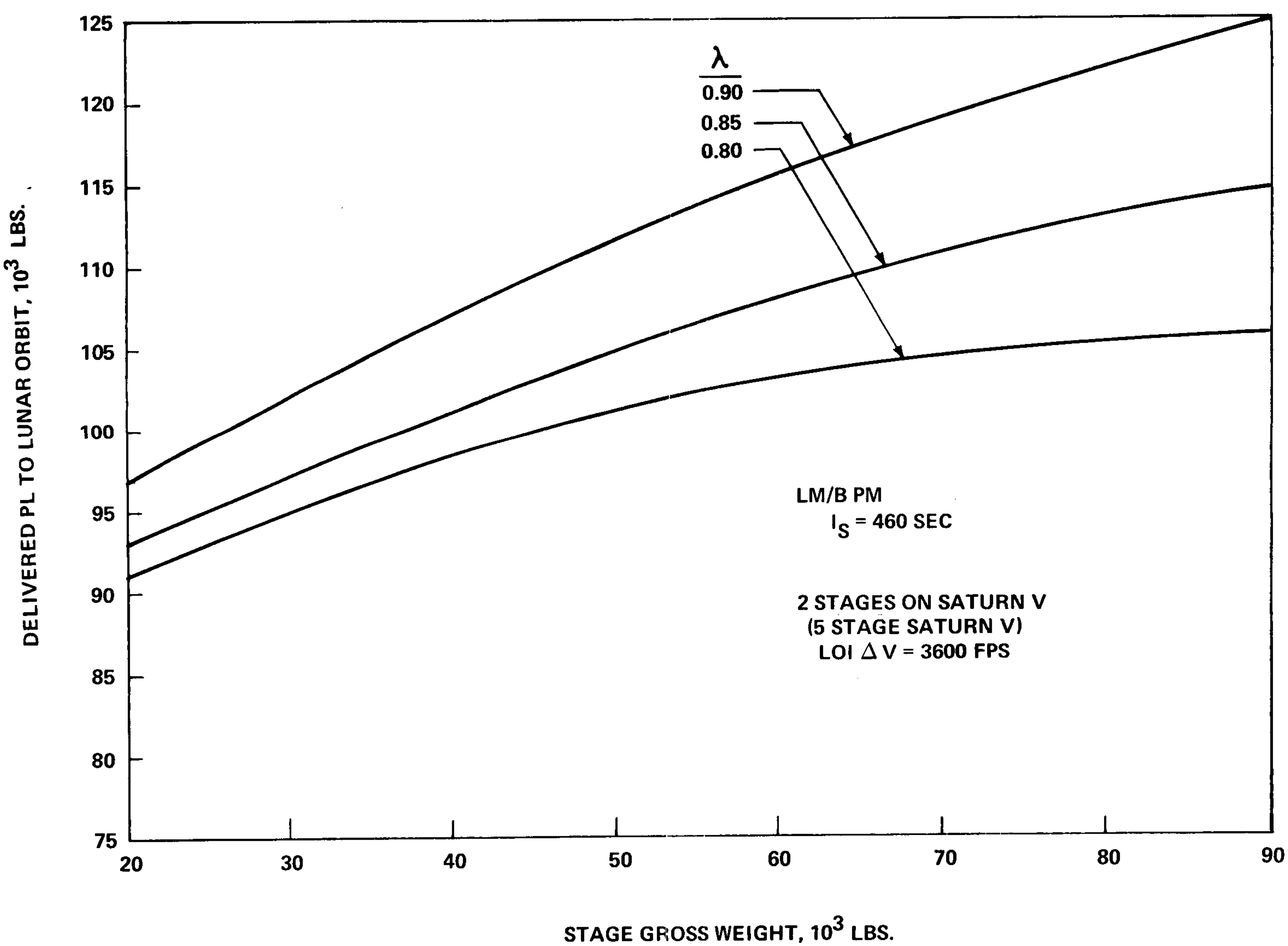

FIGURE 13 - DELIVERED PAYLOAD TO LUNAR ORBIT
5 STAGE SATURN V

OOS Mass Fraction Estimates

NASA Mission Requirements

	Inert Wt.	Mass Fraction
Unchanged OOS	4200 lbs.	0.90
Modified OOS (w/o landing legs)	7200 lbs.	0.84
Modified OOS (w/landing legs)	9700 lbs.	0.80

All NASA missions can still be adequately performed with the modified OOS, however, the stage cannot now perform the Air Force missions, even with the landing legs removed.

There are further implications in having the OOS or LM/B fit in the payload bay of the STS. The LM/B PM is to be used as a fourth stage on Saturn V, and as such will carry payloads 22 to 33 feet in diameter. If the STS payload diameter, and hence the LM/B diameter, is 15 feet, the Saturn VC stacking would consist of a 22 foot diameter third stage, a 15 foot diameter fourth stage, and a bulbous 22 to 33 foot diameter payload. Additional shrouding and structural support would then be required to assure a stable launch.

A 15 foot diameter LM/B will also present some dynamic landing problems for the lunar lander mission. The length to diameter (L/D) of the landed system (including payload) could be as high as 4 or 5. This would necessitate the use of very large and heavy landing legs to provide a sufficient margin of stability for landings.

These above considerations strongly suggest that it may not be desirable or feasible to build a single stage that can perform both the NASA LM/B missions and the Air Force OOS missions.

CONCLUSIONS

Neither the baseline nor the stretched OOS stages, currently being studied by the Aerospace Corporation for Air Force missions, can be effectively used for comtemplated missions in NASA's Integrated Space Program. This is because NASA's applications for the OOS are significantly different than the Air Force. It appears that the OOS could be modified to meet the NASA's requirements, but the resulting changes would destroy its utility to the USAF as a geosynchronous injection stage.

Detailed design studies must be conducted to determine better estimates of stage size and mass fraction so that a good estimate of its performance can be made. The structural loads imposed by the lunar lander requirement and use as an upper stage on Saturn V will require heavier structures.

The question of the Air Force use of the NASA LM/B is more complicated. The mode of operation of the Air Force missions necessitates that the stage and payload fit into the payload bay of the STS. If this is a very firm requirement, the diameter of the space shuttle will dictate the diameter of the OOS. If the shuttle payload bay remains at its current 15 feet, this would force the OOS to be a 15 foot diameter vehicle. The result would be a long fairly large L/D stage which is undersirable for lunar landings. This may also cause stacking problems for the Saturn VC configuration.

The USAF prefers to have no rendezvous and docking of the stage and payload in orbit. Also, the expended OOS will be brought back to earth for refurbishment, refueling, and reuse. The reality of these requirements must be fully determined before the question of Air Force use of the LM/B can be determined. Based on current information it appears that it may not be feasible to design a single stage that has both NASA and Air Force mission requirements imposed upon it.

A E Marks

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